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Experimental Research of Integrated Compressed Air Foam System of Fixed (ICAF) for Liquid Fuel

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Abstract

This article in view of the realistic requirement of fixed fire extinguishing system in the places of water-insoluble liquid, establishes stationary compressed air foam experiment platform in combination with the advantage of compressed air foam technology. Key component nozzle and mixing chamber of the system is designed. By cold spray test, obtains parameters of gas-liquid flow、pressure, foam mixing ratio which result in different types of foam. The division of different types of foam basis is put forward, and take drainage time as indicators, get the most stable foam parameter combination; by extinguishing experiment, get the better combination of dry foam and small nozzle whose extinguishing effect is best. The results can be guidance for production research of integrated compressed air foam and system application in combustible liquid places.

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Keywords: Compressed Air Foam, Fixed system , 25% Drainage Time

1. Introduction

Places stored of water-insoluble liquid fuel such as flammable liquid warehouse, underground parking garage, hangar has been as the focus and difficulty of the research of fire extinguishing. Once on fire, this places are easy to form flowing fire and in the danger of explosion, water system has does not apply to protect such places. Meanwhile, the place has a difficulty of extinguishing of large space, the increase of vertical height requires high jet strength for fire extinguishing installation, Greater fire hazard and loss requires a shorter starting time and corresponding release of extinguishing agent. Therefore, it is necessary to study and develop more targeted fixed fire-extinguishing facilities combining with the characteristics of the class place.

Compressed air foam extinguishing technology is a new fire extinguishing technology which receive widely attention in recent years, Its fundamental difference with traditional foam extinguishing technology is that it changed the way bubbles, fundamentally changed the structure and properties of foam, which makes the foam higher momentum and injection intensity. At the same time, because the bubble is adjustable for the dry and humidity, this technology has a broad application prospect. Studies show that the technology can be used in the following place, list as Table 1[1]： Compressed air foam technology has mobile and fixed two application forms. Abroad has fully awarded the extinguish advantage of Integrated Compressed Air Foam System of fixed(ICAF) for typical combustible liquid fire place through the contrast test of fixed compressed air foam with gas fire extinguishing system ,water mist fire extinguishing system, water system and traditional foam spray system. In China, at present, mobile compressed air foam technology application equipped in the

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engine is in progress. Through the application of compressed air foam mobile fire engine, it has been fully realized the advantage in the fire of water-insoluble liquid fuel. in Class A foam Extinguishing Agent (GB27897-2011)the test standards using compressed air foam system and technical indexes of fire-fighting requirements has been ruled and to encourage the innovation of the technology and product research and development, the disadvantage is that the standard just gives fire model of the portable foam gun requirements for extinguishing non-aqueous liquid fuel, for Integrated Compressed Air Foam System (ICAF) using for water-insoluble liquid fuel in places like the flammable liquid warehouse, garage, etc. It lacks guidance.

Table 1. Compressed air foam (CAF) application fields and typical applications

application fields	Typical application place
information technology	Emergency generator and diesel storage areas
pharmacy	Chemical processing, storage areas, laboratory
Communication and transportation	Gas stations, garage, hangar, heliport
Power generation and power transmission	Transformers, turbines, nuclear facilities
petroleum and gas	Oil depot, oil pump room, oil refineries, offshore drilling platform
manufacture	Wood processing machines, solvent storage and processing areas
construction industry	Residence, underground construction, tunnels, ancient architectural structures, tall, tall building, etc.
agriculture and forestry	Garden, stacking storage and processing areas
mining industry	Well, flammable liquid storage area

Therefore, this article based on the research status and embarks from the actual fire scenario of extinguishing, establishes fixed compressed air foam system experimental platform, to study the extinguish effects of air pressure, nozzle form and the mixing ratio of foam performance parameters for non-aqueous liquid fuel fire, In hope of promoting and enhancing products and equipment development of Integrated Compressed Air Foam System.

2. Experimental apparatus and methods

2.1. Experimental conditions

As is ruled by the Standard of Class A Foam Extinguishing Agent (GB27897-2001) , water insoluble liquid fire can be put out inside or outside the enclosure ,where wind velocity near the burner is less than 3m/s. Figure 1 shows the non-fire-extinguishment test and fire-extinguishment test of this paper. In the non-fire-extinguishment test, average temperature is 18℃and average humidity is 60%RH.While in fire-extinguishment test, average temperature is 11℃and average humidity is 52%RH.In addition, wind velocity in the compartment has been controlled within 1m/s，average temperature of foam liquid is 13℃,which has all been satisfied with the requests.

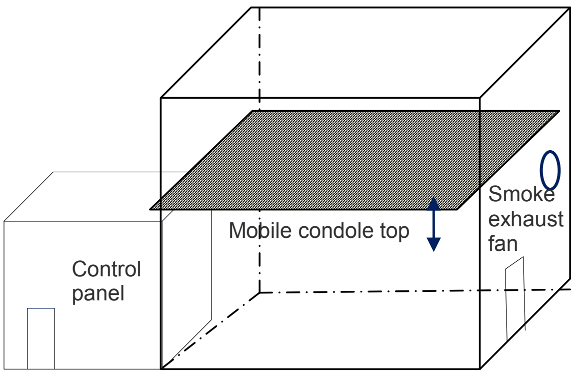


Figure. 1. test site

2.2. Experimental apparatus designs

2.2.1. Total design

Considering the stability of gas or liquid flow and equilibrium of gas or liquid pressure, compressed air bubble is produced in the form of gas drive liquid. As is showed in figure2, continuous adjustable pressure is controlled within 0-1.8Mpa by nitrogen pressure reducing valve .High pressure gas is distributed by the tee joint. One, as a reaction gas, enters the mixing chamber to realize the mixing process with foam mixture. The other enters the pressure liquid bottle to forcing foam mixture. Assuming the liquid bottle pressure loss and pipe network of frictional head loss are all ignored, pressure of foam mixture flowing out of the bottle equals the high pressure nitrogen flowing into the bottle, which is also equal to the pressure of high pressure gas in the front of mixture. Then high pressure nitrogen in the mixing chamber can form compression foam by the distributing of SK static mixing chamber, and finally release through the nozzle. Gas and liquid flow can be adjusted into five files by the liquid bottle valve. One file means the maximum of opening and five file means the minimum. pipe network of frictional head loss is measured by pressure gauge. Gas flow is measured by the Coriolis mass flow meter. Fluid flow is measured by turbine flowmeter.Figure3 shows the experimental apparatus.

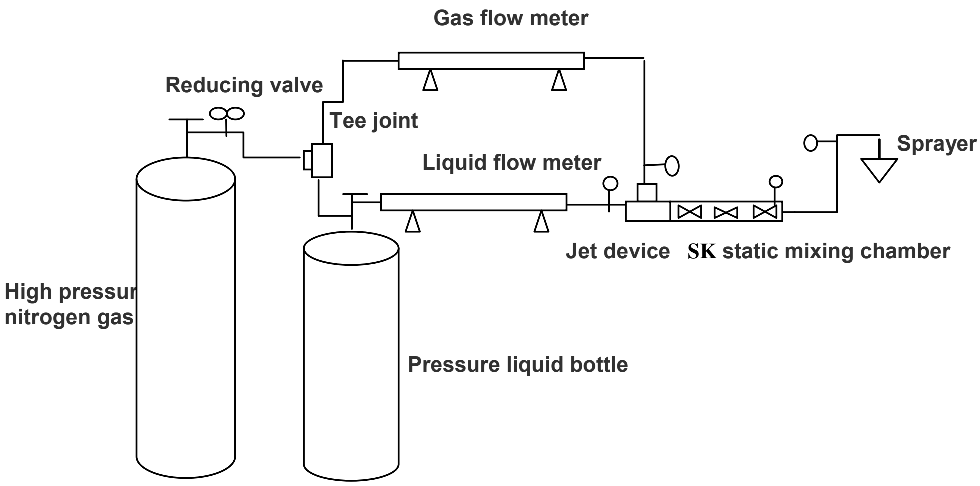


Figure. 2. The principle diagram of ICAF

Figure. 3. The experiment platform system

2.2.1. Key part design

Static mixing chamber is adopted in the mixing chamber design. Its structure design is referred to Static Mixer National Sandard (JB/T 7660-1995).Figure4 shows the molding products. Tube wall is made of transparent PVC, its diameter is

40mm and inner diameter is 33.6mm.Amount of internal mixing unit is six; its effective mixing length is 330 mm. Both ends use DN32 in the form of one inch outside wire connection. Total length of mixture is about 370mm.Figure5 shows the foam production.

Figure. 4. SK type static mixer mixing chamber

Figure. 5. jet mixing chamber to form bubble

As a reference of fountain nozzle design for fireworks, nozzles in this test are made of copper and nylon. The design parameter include nozzle arc α, radius r, diameter deep h and jet hole design. Interface uses inside wire connection, its principles showed in figure 6.Relavent references indicate that main factors influencing the sprinkler area are nozzle radius and injection hole size. As the size of the compressed air bubble is between 0 to 2 mm, 3 mm and 5 mm injection hole are designed in accordance with the principle of uniform design. This test designs five different nozzles. From one to three nozzles, arc is unchangeable. α=64° -74° .Radius is respectively 20mm, 24mm and 39mm.Nozzle 4 and nozzle 5 designs are the same with nozzle3. Injection hole of nozzle 3 is 5mm.Nozzle 5 is not designed uniformly. Size of its center and first three circles is 5mm, while the fourth and fifth circle is respectively 3mm and 2mm, which is showed in table2.

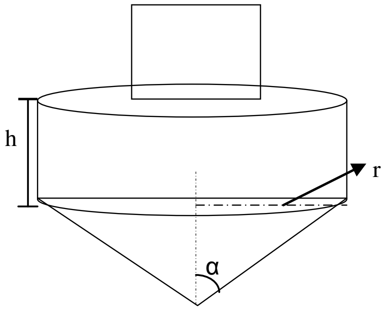


Figure. 6. nozzle design schematic diagram

Table 2. Different forms of nozzle shape parameter table

serial number	1	2	3	4	5
picture					
name	Small spray	Medium	Big nozzle	5mm perforation	no uniform
r	20	24	39	39	40
h	7	7	16	16	17
α	69.5	73.0	65.8	65.8	64.8

3. The cold experimental study

3.1. Cold working condition of experiment design

Because the compressed air foam system bubbles in gas-liquid mixing room and spread out in the nozzle, to study the effect of nozzle whether affect the performance of the foam, or just have the effect of distribution of foam, first designed the experiment to determine the function of nozzle, just as Table 3.

Table 3. Working condition of the function test

operating pressure（Mpa）	opening	mixing ratio（%）	Nozzle type
1.0	1max	0.4	No nozzle
1.0	1max	0.4	Small spray

To explore the influencing factors of foam stability, designed with foam 25% drainage time as indicators of the orthogonal experiment. Considering system is divided into nitrogen cylinder pressure control and the control of hydraulic cylinder valves of the opening of, so these two quantities as test variables. Due to the properties of the foam concentrate was also significantly influence the performance of the foam, so the foam liquid mixing ratio as the experimental variables to consider. By the nozzle function test above, it found that the shower nozzle impact on the performance of the bubble, so there will be five different nozzles as another important factor. Finally choose orthogonal test table L25(56), the header design is Table 4

Table 4. the orthogonal experiment factors - level table

factor / level	A= operating pressure (Mpa)	B=opening	C= mixing ratio (%)	D= Nozzle type
1	1.2	1	0.4	no uniform
2	1.1	2	0.6	5mm perforation
3	1.0	3	0.8	Big nozzle
4	0.9	4	1.0	Medium
5	0.8	5	1.2	Small spray

3.2. The analysis and results of cold experiment

3.2.1. Nozzle function test results

With the density of foam and drainage time as a measure Observations the nature of the bubble in same condition in addition to have the nozzle or not. It turned out that: when there is no nozzle, Bubble falls down verticality. Drainage time is longer and the bubble density is smaller when compared with nozzle. The reason may be the orifice of nozzle has damage the bubble structure. The nozzle make the foam liquid membrane rupture when distribute of foam at the same time, formatting water drop which is the concentration of foam drainage in the bubble. Thus makes the drainage time shortened.

3.2.2 Foam performance test results

The parameters of drainage time, gas and liquid flow rate and the pressure gauge have been measured in the experiment, which is listed in table 5.

Table 5. Drainage test results summary

No.	pressure	opening	mixing ratio	Nozzle type	Test order	liquid flow m3/h	gas flow g/s	fluid pressure （Mpa）	gas pressure （Mpa）	Drainage time	Q_g/Q_l	E=1/ρ =V/M
1	1.2	1	0.4	no uniform	14	2.076	2.562	0.420	0.401	78	3.601	7.742
2	1.2	2	0.6	5mm	15	1.670	2.558	0.376	0.358	104	4.470	5.797
3	1.2	3	0.8	Big nozzle	16	0.549	3.050	0.180	0.166	111	16.202	5.430
4	1.2	4	1.0	Medium	17	0.220	3.273	0.160	0.140	164	43.353	3.670
5	1.2	5	1.2	Small spray	18	0.139	3.273	0.136	0.126	248	68.759	2.419

6	1.1	1	0.8	Medium	9	2.158	2.166	0.439	0.399	85	2.930	7.101
7	1.1	2	1.0	Small spray	10	1.806	2.298	0.388	0.352	89	3.713	6.742
8	1.1	3	1.0	no uniform	12	0.900	2.729	0.220	0.204	105	8.849	5.742
9	1.1	4	0.4	5mm	11	0.207	2.750	0.083	0.062	97	38.803	6.186
10	1.1	5	0.6	Big nozzle	13	0.098	2.969	0.076	0.057	87	88.313	6.936
11	1.0	1	1.2	5mm	4	2.056	1.988	0.408	0.370	86	2.822	6.977
12	1.0	2	0.4	Big nozzle	3	1.746	2.170	0.358	0.320	84	3.627	7.143
13	1.0	3	0.6	Medium	2	0.796	2.463	0.200	0.177	94	9.035	6.383
14	1.0	4	0.8	Small spray	1	0.219	2.466	0.118	0.100	104	32.918	5.797
15	1.0	5	1.0	no uniform	19	0.085	2.468	0.080	0.067	147	84.725	4.096
16	0.9	1	0.6	Small spray	5	1.918	1.735	0.360	0.330	107	2.639	5.634
17	0.9	2	0.8	no uniform	20	1.767	2.014	0.356	0.320	91	3.326	6.630
18	0.9	3	1.0	5mm	6	0.771	2.195	0.181	0.168	110	8.307	5.479
19	0.9	4	1.2	Big nozzle	7	0.260	2.282	0.140	0.119	128	25.582	4.688
20	0.9	5	0.4	Medium	8	0.082	2.257	0.058	0.032	43	80.023	14.118
21	0.8	1	1.0	Big nozzle	21	1.893	1.571	0.328	0.300	93	2.422	6.452
22	0.8	2	1.2	Medium	22	1.699	1.640	0.290	0.270	105	2.817	5.742
23	0.8	3	0.4	Small spray	23	0.881	2.010	0.180	0.170	83	6.661	7.229
24	0.8	4	0.6	no uniform	24	0.460	1.995	0.120	0.105	111	12.652	5.430

25	0.8	5	0.8	5mm	25	0.108	2.043	0.073	0.059	149	55.097	4.027

Drainage time reflects the stability of the foam, the longer of the drainage time the more stable of the foam, reflect in the form of a dry bubble which more suitable for heat insulation protection and isolation.

Using orthogonal test software assistant to analysis the test, the average time and the difference of the maximum and the minimum of drainage listed as table 6.

Table 6. The orthogonal experiment results

Serial number	Operating pressure (Mpa)	3. Opening	4. Mixing ratio (%)	5. Nozzle
			$L_{25}(5^6)$	
The average drainage K1	281.2	179.0	153.6	211.8
The average drainage K2	184.6	6. 218.2	7. 200.4	8. 218.0
The average drainage K3	205.6	9. 175.4	10. 215.4	11. 200.8
The average drainage K4	190.8	12. 241.0	13. 240.6	14. 195.6
The average drainage K5	216.0	15. 269.0	16. 268.4	17. 252.0
max- min R	96.6	18. 90.0	19. 114.8	20. 56.4

With the difference, the impact of various factors on drainage time can be ordered. The most important factor for drainage time is mixing ratio, followed by operating pressure, opening Valve also influence the drainage time, which listed in third ,the minor factors is nozzle type.

To show the level of various factors on the influence of drainage time intuitively, draw index factors affect curve as shown in figure 7: which take average drainage time as vertical coordinates, level of various factors as the abscissa.

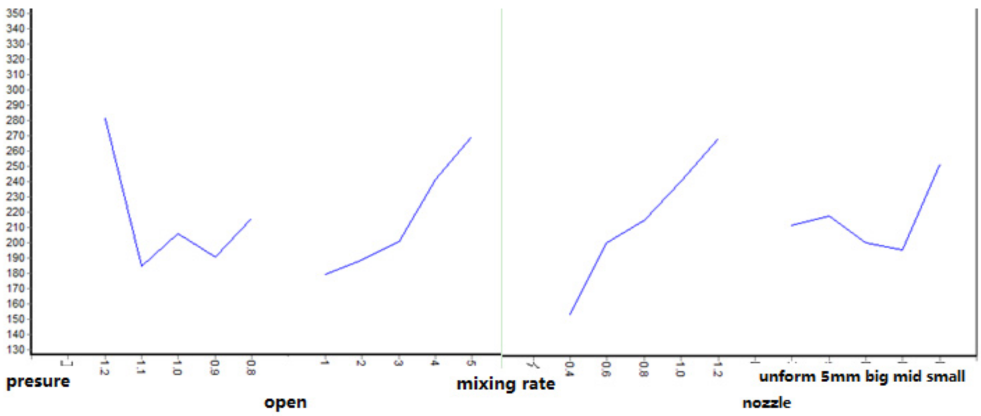


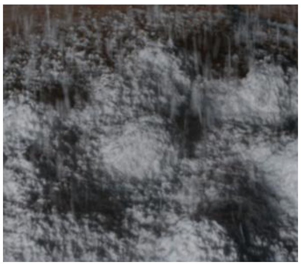
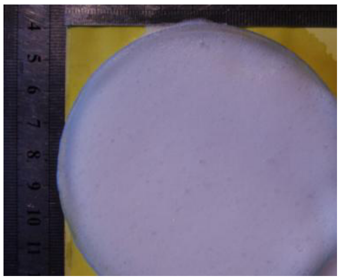
Figure. 7. index factors affect curve

what be concluded from the figure is that: as hydraulic cylinder valve door opening smaller and the bubble mixing ratio bigger, drainage time increases significantly, the operating pressure and nozzle type have little influence of drainage time. Therefore, the drainage parameters combination for long bubble is : Pressure 1.2 Mpa, the opening is 5, mixing ratio of 1.2%, nozzle for the small nozzle. Considering the energy consumption of high pressure system, adjust the system pressure to 1.0 Mpa. Nozzle selection in addition to affect the drainage time, its protection radius is different. The largest radius of protection is the uneven nozzle which is 0.80 m, followed by the small nozzle, and is 0.72 m. Thus considering from protection area, the uneven nozzle will also be selected. The bubble condition and images comparison shows in table 7 and table 8:

Table 7. Wet foam parameter list

operating pressure=1.0Mpa	mixing ratio =0.6%	
opening=2	Nozzle type = Small spray	
Sprayed pictures	The ground build-up	The bubble size
		

Table 8. Dry foam parameter list

operating pressure =1.0Mpa	mixing ratio =1.0%	
opening=min5	Nozzle type = Small spray	
Sprayed pictures	The ground build-up	The bubble size
		

Images show intuitively that wet bubble is liquid and bubble size is uneven. Dry foam is illiquid, bubble size is uniform, therefore dry foam is more stable foam, and drainage time is longer.

Experimental results also verify the American standards of high, medium and low foam - 2010 edition, (NFPA11) and the definition of foam dry and humidity of strong companies in the United States[2] According to the division NFPA11[3]

and strong company standards, combined with the experimental results, this article divide bubbles into the following three categories, just as table9:

Table 9. Bubble type and classification standard

Foam type	The main parameters and scope	Bubble character description
Wet bubble	Q_g/Q_l: 1-8,mixing ratio 0-0.4%, 25% drainage time :less-than 85s	Appearance is similar to water, There is a small amount of foam body, In the vertical surface adhesion is poor
Medium bubble	Q_g/Q_l: 9-30,mixing ratio 0.4-0.8%, 25% drainage time: less-than 105s	After the jet surface smooth, Melt butter shaped
dry bubble	Q_g/Q_l:greater than30 mixing ratio 0.8-1.2%, 25% drainage time: greater than 105s	After the injection surface of ups and downs, very dry, Wool or cotton shaped, Lightweight ,Strong adhesion, liquidity is poor

Also, take gas flow, liquid flow, gas pressure, and liquid pressure before mixed as an index, analysis of the influence of operation pressure, the liquid bottle opening, mixing ratio, and type nozzle. Get the following rule: With the decrease of the opening and the decrease of the operating pressure, the pressure of gas and liquid before mixed is reduced; Operating pressure has a significant effect on gas flow, the smaller the pressure, gas flow rate is smaller, but has no effect on the liquid flow; The mixing ratio and nozzle type influence little.

4. Fire-extinguishing test

4.1 .Oil test with no extinguishment

Select 50 cm of the diameter of the disc, built-in 2000 ml water about 1 cm water cushion layer formation, At the same time, add 2000ml, 93 # gasoline and light. Thermocouple placed in the center of the oil pan, from top to bottom number 1-8, 20 mm intervals. Thermal radiation is 1.5 m from the center of oil pan, from top to bottom is no. 1-4. Figure 8 describes the gasoline combustion process. Figure9 describes the flame temperature time curve.

Figure. 8. gasoline combustion processes.

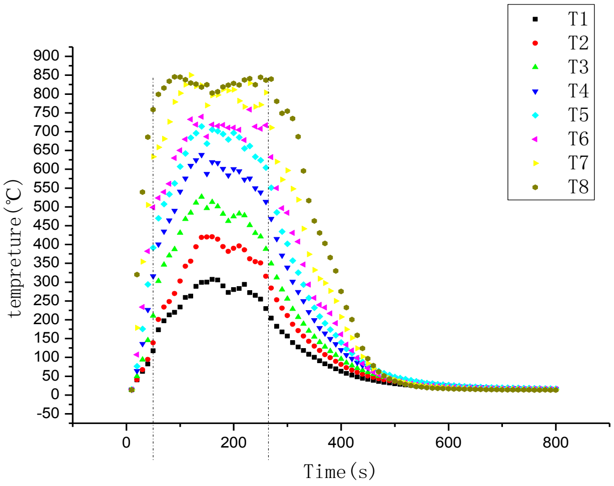


Figure. 9. The flame temperature time curve

As can be seen from the temperature time curve, Gasoline combustion flame peripheral temperature up to 850 ℃ or so, In the thermocouple temperature 8 which is closest to the oil pan as the standard, It can be seen that the burning oil pan to stabilize at around 60 s, when burning into the 260 s, started die out, and temperature drop. Consistent with GB27897-2011 “class A foam extinguishing agent”.

4.2. The influence of bubble type of fire

For the study of the system optimal performance parameters of the bubble, and the influence of bubble shape on the fire extinguishing time, based on three different forms of foam, different types of foam fire extinguishing experiment is designed, The test results as shown in table 10

Table. 10. different types of foam fire extinguishing experiment result

No.	opening	mixing ratio (%)	operating pressure	Nozzle type	gas flow g/s	Liquid flow m^3/h	Foam type 21.	extinction time (s)
1	2	0.4	1.0	Small	2.232	1.697	Wet bubble	100
2	3	0.8	1.0	Small	2.702	0.786	Medium	45
3	3	1.0	1.0	Small	2.726	0.622	Medium	40
4	5	1.0	1.0	Small	2.738	0.364	dry bubble	29

It can be seen from the experimental results, the dry foam extinguishing effect is best, the shortest extinguishing time for 29 s.

4.3. The influence of nozzle type of fire

In order to further the analysis the effect of nozzle form for extinguishing time, more than a group of dry foam which extinguishing the fastest combined with different nozzles are chosen in the form of fire extinguish and the results as shown in table 11:

Table 11. different nozzles fire extinguishing experiment result

No.	opening	Mixing ratio	pressure	Nozzle	gas flow	Liquid flow	extinction time
1	5	1	1.0	Medium	2.761	0.3308	42
2	5	1	1.0	Big nozzle	2.680	0.3807	30
3	5	1	1.0	5mm	2.742	0.3820	70
4	5	1	1.0	no uniform	2.745	0.3555	23
5	5	1	1.0	Small	2.738	0.364	29

As you can see from the result of fire, When using non-uniform nozzle, extinguishing time is shortest .In non-aqueous liquid fire extinguishing, therefore, can choose dry foam, non-uniform sprinkler nozzle, at this point, the protection of a single nozzle radius of 0.9 m, Figure 10 shows the fire extinguishing process.

Figure. 10. shows the fire extinguishing process.

5. Conclusions

Based on non-soluble liquid fuel fire extinguish demand, this paper developed an Integrated Compressed Air Foam System of fixed(ICAF), the key parts of the system is designed, the key parameters of the system is given and the bubble dividing basis is listed which divided into dry foam, foam wet bubble and medium type. In extinguish fire experiment for non-soluble fuel, the effect of dry foam is better, in different forms of nozzle, the non-uniform nozzle protection area is larger, extinguishing time is shorter, The shortest extinguishing time is 23 s. The results promote compressed air foam technology apply to fixed reference system to provide the experimental and equipment basis, provide technical guidance for the transition of the technology research and development. The next step should be based on characteristics of liquid storage, underground garage and other places, more nozzle engineering simulation experiment should be carried out, and provide a reference for engineering application and network design.

References

[1] Gao Yang. Study on Compressed Air Foam Fire Extinguishing System and Heat Insulation Performance, Chinese People's Police Force Academy, May. 2012.
[2] Fang dong-yun. Study on Fixed-pipe Compressed Air Foam System, Chinese People's Police Force Academy, May. 2013.
[3] NFPA11, 2010. Standard for Low-, Medium-, and High-Expansion Foam, USA.